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13. ABSTRACT (Maximum 200 words)

We have undertaken a theoretical study of the resonance properties of electronic and optoelectronic devices to understand the processes which control the resonance widths. Initially we considered quantum dot single-electron transistors and derived a universal statistical distribution of widths which has recently been confirmed experimentally. Next we applied related concepts to understand the long-lived "whispering gallery" resonances of optical resonators. This had led to the proposal of a new class of micro-cavity resonators, ARCs (Asymmetric Resonant Cavities) which have highly directional emission and controllable Q values. These resonators may have applications to micro-lasers, integrated optics and fiber-optic communications.

14. SUBJECT TERMS
Single electron transistors, quantum dots, resonant tunneling, micro-cavity optics.

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Final Progress Report - Statistical Properties of High-Mobility Quantum-Effect Devices

A. Douglas Stone, PI - 10/16/96 - U.S. Army Research Office

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Problem statement:

The aim of the project was a theoretical study of the resonance properties of electronic and optoelectronic devices in order to understand what fundamental processes determine the resonance widths and how they can be controlled. More specifically the initial topic of study was the resonances of semiconductor quantum dots which function as single-electron transistors due to the Coulomb blockade effect [1, 2, 3, 4]. In such devices the amplitude of the resonances was observed to fluctuate strongly for unknown reasons. Since the resonances are thermally-broadened the amplitude fluctuations were related to fluctuations in the intrinsic width [5, 6]. We had conjectured [7] that the amplitude fluctuations were due to chaotic fluctuations in the quasi-bound state wavefunctions which would obey a universal statistical law as long as the dot potential was sufficiently irregular. This study led us to the second stage of the project in which we used the concepts developed for these single-electron resonators to predict the properties of deformed optical resonators. In particular, we wanted to understand the broadening (Q-spoiling) of the long-lived whispering gallery resonances of the dielectric optical resonators used in micro-disk lasers and other optoelectronic devices [8].

Summary of significant results:

- Microscopic calculations confirmed the existence of a universal distribution of resonance widths for chaotic quantum dots [9, 10] and subsequent experiments obtained excellent agreement with the theory [11, 12].
- The calculations also revealed different behavior for the resonances of quantum dots

which were only partially chaotic [10]. Although semiconductor quantum dots are not currently well-enough controlled to test this prediction, the theory had immediate implications for deformed optical resonators.

- The two major problems with optical devices based on dielectric microcavities are their extremely high intrinsic Q values and their isotropic emission properties [15]. Using a model similar to our earlier work [9], we were able to adapt ideas from chaos theory and wave chaos theory to predict the resonance width and onset of directional emission in deformed microcavity resonators [13, 14]. Very recently experiments by Richard Chang's group at Yale have confirmed the highly directional emission from deformed lasing liquid columns [16].

- Our work has led us to propose the development of a new class of *asymmetric cavity resonators* (ARCs) which may be of great use in fiber-optic telecommunications and integrated optics. These resonators are compact, have controllable Q values which may be tuned to the desired data transmission rate, and highly directional emission [17].

- As another direction for the theory we predicted the possibility of Fano lineshape resonances in double-barrier heterostructure resonant tunneling [18, 19]. This prediction has not yet been tested experimentally.

Publications Supported:

1. "Quantum-Chaotic Scattering Effects in Semiconductor Microstructures", H.U. Baranger, R.A. Jalabert and A. D. Stone, CHAOS, **3**, 665 (1993).

2. "Universal Fluctuation Effects in Chaotic Quantum Dots", A. D. Stone and H. Bruus, Surf. Sci., **305**, 490, (1993).

3. "Quantum Chaos in a Deformable Billiard: Applications to Quantum Dots", H. Bruus and A. D. Stone, Phys. Rev. B **50**, 18275 (1994).

4. "Resonance Lineshapes in Quasi-One-Dimensional Scattering", J.U. Nöckel and A.D. Stone, Phys. Rev. B **50**, 17415 (1994).

5. "Fano Resonances in Transport across a Quantum Well in a Tilted Magnetic Field", J.U. Nöckel and A.D. Stone, Phys. Rev. B. **51**, 17,219 (1995).

6. "Q-spoiling and Directionality in Deformed Ring Cavities", J.U. Nöckel, A.D. Stone and R.K. Chang, Optics Letters, **19**, 1693 (1994).

7. "Ray Chaos and Q-spoiling in Lasing Droplets" A. Mekis, J.U. Nöckel, G. Chen, A.D.Stone and R.K.Chang, Physical Review Letters, 75, 2682 (1995).

8. "Directional emission from asymmetric resonant cavities" J. U. Nöckel, A.D.Stone, G. Chen, H.L. Grossman and R.K.Chang, Optics Letters, **21**, 1609 (1996).

Participating Scientific Personnel:

1. PhD students: J.U. Nöckel (PhD 1996).

2. Postdoctoral Fellows: Dr. Henrik Bruus (partial).

3. A. Douglas Stone (partial summer salary). The PI was elected to APS Fellowship during this grant period.

Inventions: None during the grant period.

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